

STATIC AEROELASTICITY OF A COMPOSITE OBLIQUE WING
IN TRANSONIC FLOWS

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INTRODUCTION

One aircraft configuration that shows great promise in achieving high performance is that of an asymmetrically swept wing, shown in Figure 1 (ref. 1, 2). When compared to conventional swept wings, these advantages include higher lift-to-drag ratios and reduced takeoff and landing speeds, which translate into increased performance in terms of fuel consumption, loiter time, range, etc. However, the oblique wing has a number of disadvantages because of its asymmetric configuration. Referring to Figure 1, consider the swept oblique wing shown to have an upward bending deflection, such that lines AB and A'B' represent lines of constant upward bending displacement. For the aft-swept portion of the wing, the airflow will see line CB. Since point B deflects upward more than point C (due to the bending displacement increasing from the wing pivot to the wing tip), the airflow will see a downward twist along CB due to the bending displacement. This bend-up/twist-down phenomenon is referred to as "wash-out". The forward-swept wing, on the other hand, will have the airflow seeing a nose-up twist due to bending since point C' deflects more than point B'. This bend-up/twist-up is called "wash-in". The increase in angle of attack associated with wash-in will increase the wing load, which will tend to increase the bending deflection and hence wash-in twist even further. Thus, divergence becomes a concern with the forward-swept wing (e.g., the X-29). Also, because the two portions of the wing undergo different bend/twist behaviour, the swept oblique wing will have a roll imbalance due to the different loadings on the forward- and aft-swept portions of the wing.

The question is, then, how to best achieve maximum stability and roll equilibrium without compromising performance. Using aeroelastic tailoring to enhance aeroelastic stability and control has been demonstrated in several analyses, especially for the forward-swept wing (ref. 3, 4, 5). Since the oblique wing has a forward-swept half, aeroelastic tailoring is also potentially beneficial for an oblique wing design. For a basic discussion of aeroelastic tailoring, see references 6 and 7.

TYPICAL ASYMMETRICALLY SWEEPED WING

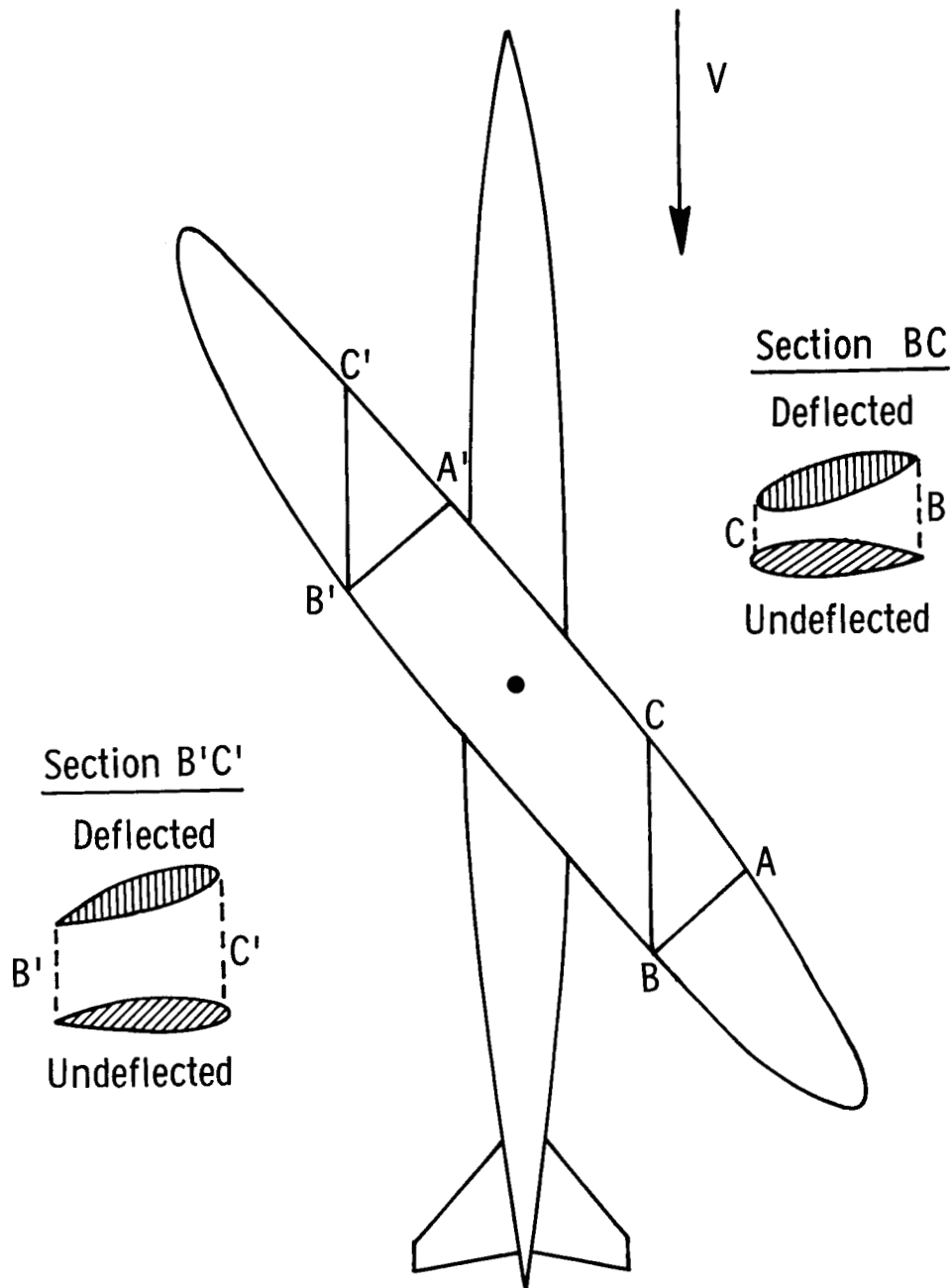


Figure 1

STATIC AEROELASTIC COMPUTATIONAL PROCEDURE

The static aeroelastic computational procedure (Figure 2) was developed to study the basic effects of aeroelastically tailoring an oblique wing through the use of composite materials. First, the geometry is defined for the oblique wing, which may have deflected control surfaces. In this analysis the oblique wing model has two outboard ailerons deflected an equal but opposite amount as input by the user of the computational procedure. This geometry is then submitted to the full potential code FLO22 for aerodynamic analysis (ref. 8, 9, 10). The output is a pressure distribution over the wing. After the pressure load has been converted to equivalent loads P , an equivalent plate program, developed by Dr. Gary Giles at NASA-Langley, is invoked for each half of the oblique wing (ref. 11). From the structural definition of the wing (input by the user) and the equivalent loads, the plate program calculates a set of coefficients C , from which the displacement of the wing due to the aerodynamic loads is defined in polynomial form. The wing shape is then deflected according to the calculated displacement. This deformed wing geometry is then input to FLO22 for aerodynamic analysis, and the aeroelastic procedure is repeated until a converged deformed shape has been obtained for the flexible composite wing. Usually only 3-4 aeroelastic iterations are required before a converged shape, i.e., a shape consistent with the aerodynamic loads calculated by FLO22, is reached.

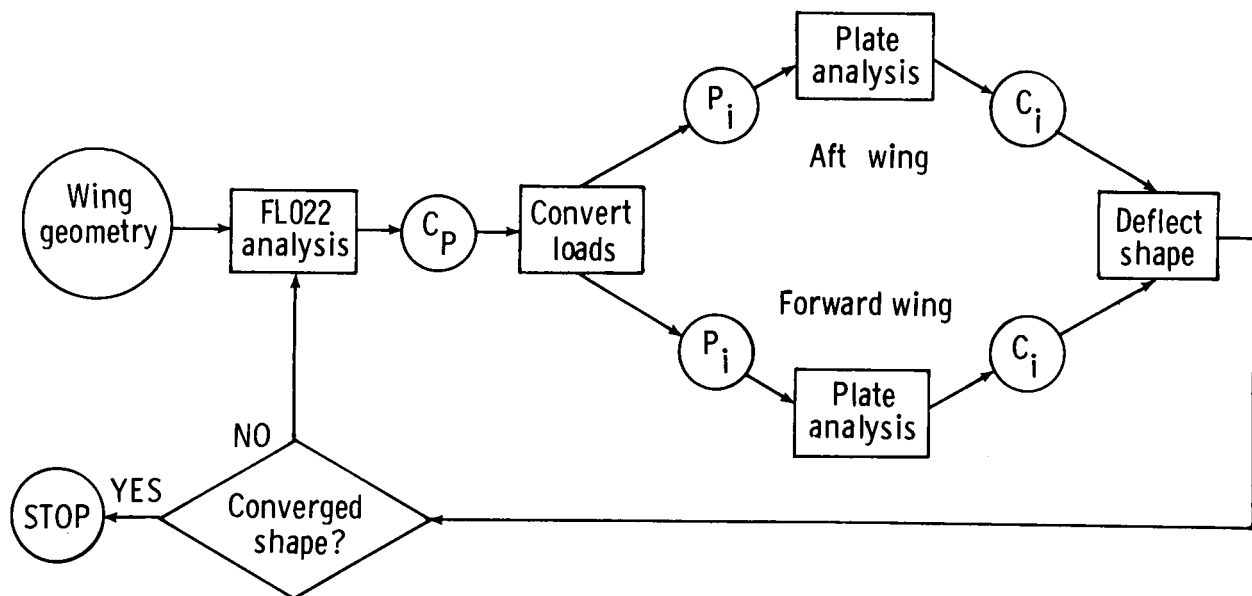


Figure 2

APPLICATION OF AEROELASTIC TAILORING

Each aeroelastic computational run described above involves one aileron deflection and one value of the amount of aeroelastic tailoring applied to the wing. This application of aeroelastic tailoring is achieved in this analysis by simply rotating the basic composite skin laminate of the wing by an angle θ (see figure below). Recall that a swept oblique wing exhibits a roll imbalance. If asymmetric composite tailoring is applied to the wing, i.e., the aft-swept half of the wing is given a wash-in structure to counteract its wash-out twist due to bending (recall figure 1), and the forward-swept half is given a wash-out structure to alleviate its wash-in twist due to bending, the oblique wing will aeroelastically desweep in that it will aeroelastically behave as if the wing had less sweep. This is desired since an unswept oblique wing does not have a roll imbalance. Thus, asymmetric tailoring could alleviate the roll problem of the oblique wing by an aeroelastic desweeping, while the wing would still retain the aerodynamic advantages of being swept. The tailoring is simply applied by rotating the composite laminate an angle θ as shown below. (Figure 3.) The wing can thus be trimmed in roll with aileron deflection or asymmetric tailoring, or a combination of both, as seen next.

APPLICATION OF WASH-OUT/WASH-IN TO COMPOSITE WING

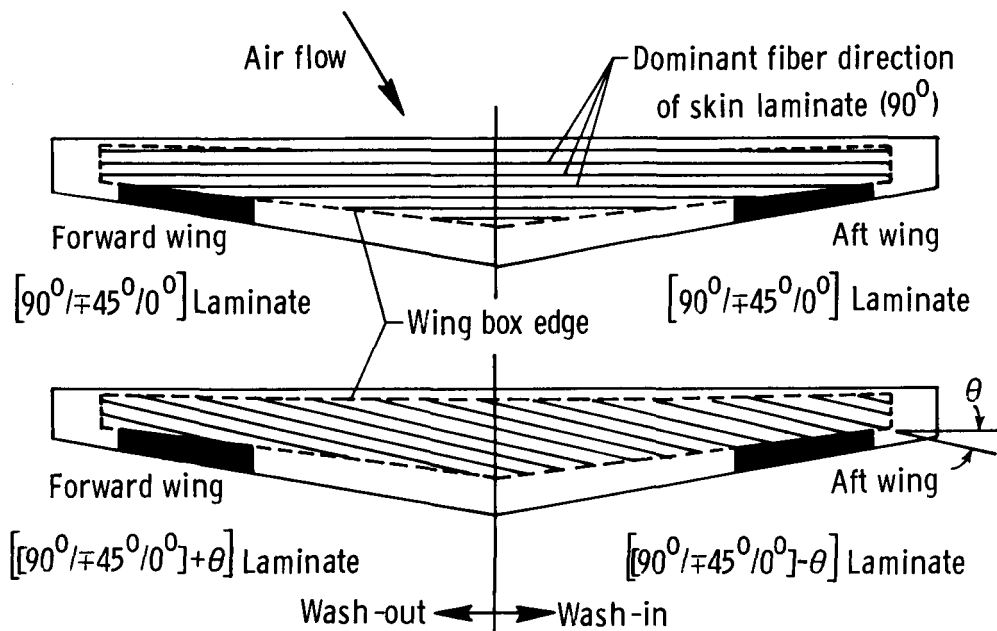


Figure 3

OBLIQUE WING ROLL TRIM ANALYSIS

The main intent of this analysis is to study the performance of an oblique wing in roll trim with asymmetric composite tailoring. Both cruise and maneuver conditions are explored, the cruise case (1g) having a dynamic pressure of 215 psf and an angle of attack of -0.25 deg, and the maneuver case (2.25g) having a dynamic pressure of 280 psf and a 3 degree angle of attack. Both conditions have a Mach number of 0.75. The oblique wing model has an aspect ratio of 10 and a taper ratio of 0.4, and incorporates the supercritical airfoil OW 70-10-12. The wing structure consists of wing skins made of a typical graphite-epoxy composite. The composite lay-up and planform shape were shown in figure 3. The performance of the wing is measured by four aerodynamic, control and structural parameters. Aerodynamically, the pressure (induced) drag is noted to see if aeroelastic tailoring results in an increase or decrease in drag for the wing. From the controls viewpoint, the ability of the ailerons to generate a rolling moment (control effectiveness) and the hinge moments on the control surfaces are used to measure performance. The hinge moments dictate the actuator system for the wing. A decrease in hinge moment could result in a lighter actuator system, which is a benefit because of a decrease in weight. Structurally, the stress level f in the composite skins is noted, defined as

$$f^2 = \left(\frac{\sigma_{11}}{X}\right)^2 + \left(\frac{\sigma_{22}}{Y}\right)^2 - \left(\frac{\sigma_{11}}{X}\right)\left(\frac{\sigma_{22}}{X}\right) + \left(\frac{\tau_{12}}{S}\right)^2$$

where σ and τ are the stresses in the composite layer, and X , Y and S are material constants (ref. 12). Before noting how these performance parameters are affected by aeroelastic tailoring, conditions for roll equilibrium are first obtained by numerous aeroelastic computational runs. Figure 4 shows combinations of aileron deflection δ and laminate orientation angle θ required to trim the oblique wing in roll.

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OBLIQUE WING TRIM CONDITIONS

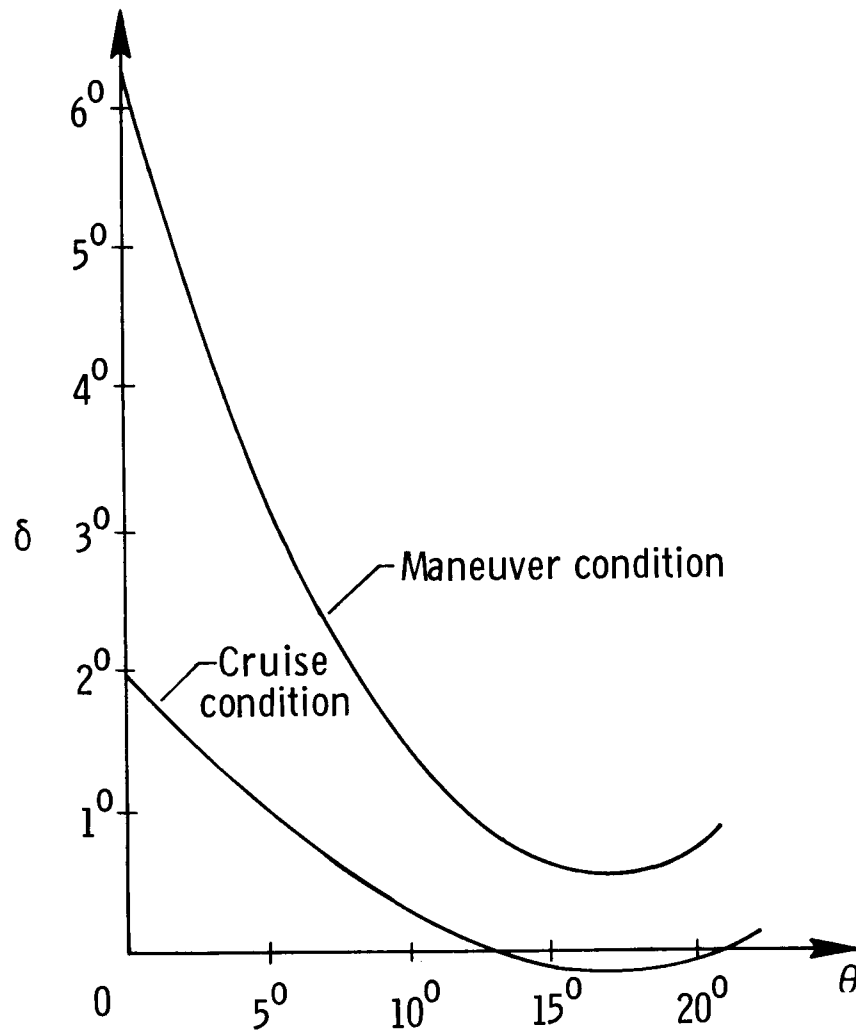


Figure 4

AERODYNAMIC PERFORMANCE

Figure 5 plots the pressure drag coefficient versus the laminate orientation angle for the oblique wing in roll trim. An aileron deflection angle is associated with each laminate orientation angle for cruise and maneuver according to figure 4. For both cruise and maneuver, the pressure drag remains relatively flat. This occurs because the twist distribution across the wing is basically the same for the roll-trimmed oblique wing regardless of what θ - δ combination is used to achieve that roll equilibrium. The drag at $\theta=20$ deg is about 3 or 4 counts higher than at $\theta=0$ deg for the cruise and maneuver conditions (one drag count equals a drag coefficient of 0.0001). However, it must be remembered that the pressure drag does not include boundary-layer effects or drag from flow separation. Referring to Figure 4 again, a fair amount of aileron deflection is required for small laminate orientation angles, especially for the maneuver case. We would suspect that higher aileron deflections would result in a larger boundary layer and a greater likelihood of flow separation, which would result in an increase in drag not accounted for in the aerodynamic analysis of FLO22. Thus, aeroelastic tailoring could potentially result in less drag because of the reduction in aileron deflection needed for roll trim.

PRESSURE DRAG VERSUS θ

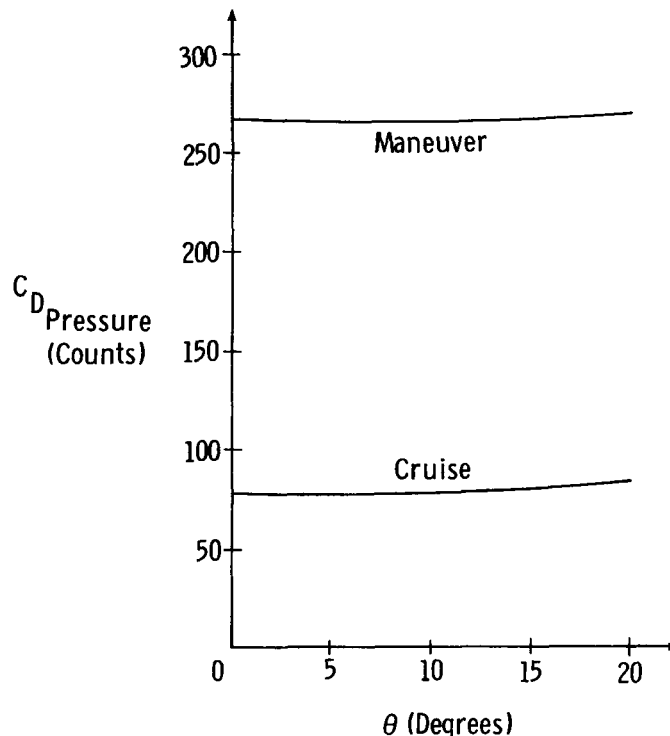


Figure 5

CONTROL PERFORMANCE

The hinge moment coefficient versus laminate orientation angle is plotted in Figure 6 for the oblique wing in roll trim. The hinge moment would determine the actuator system needed for the control surfaces. Since the actuator would be the same for each aileron, consider the higher loaded aileron, which is on the aft wing. We see that for both cruise and maneuver the hinge moment is reduced as the composite laminate is rotated due to the reduction in aileron deflection. Because of the reduced hinge moment, a smaller, lighter actuator could be used giving a weight savings. Aeroelastic tailoring can thus give a performance advantage by not only reduced aileron deflection but also a weight reduction by the resulting decrease in hinge moments. Additional results not shown here also indicate the ailerons will not suffer any significant reduction in their ability to produce a rolling moment if the wing is aeroelastically tailored.

HINGE MOMENT COEFFICIENT VERSUS θ

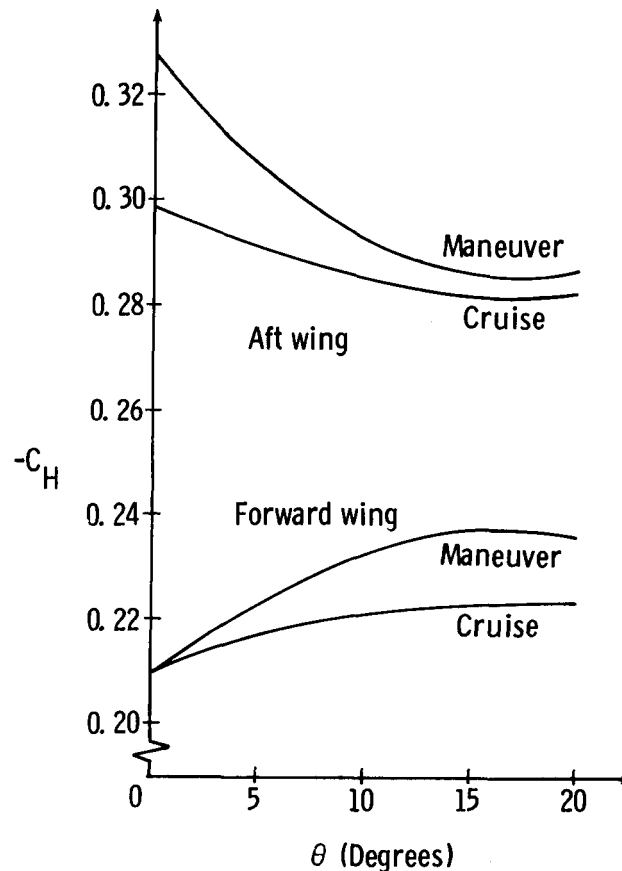


Figure 6

STRUCTURAL PERFORMANCE AND CONCLUSIONS

The effect on the stress level in the composite skins due to changing the laminate orientation angle is shown in Figure 7 for the oblique wing in roll trim. The figure depicts the maximum stress level occurring in the composite laminate, which generally occurs in the composite layer whose fiber direction is directed mainly along the chord of the wing. It is seen that the maximum stress level increases as the composite laminate is rotated. This is viewed as a disadvantage because a higher stress level would imply that the skin thickness must be increased to obtain the desired strength and factor of safety, resulting in more weight.

Thus, performance trade-offs do exist in the application of aeroelastic tailoring to the oblique wing. Tailoring the wing results in a decrease in the aileron requirements on the oblique wing for roll trim, leading to a reduction in aileron hinge moments. This implies a weight reduction since a smaller actuator could be used. The decreased aileron deflection could also mean that aeroelastic tailoring gives a drag reduction because of the smaller boundary layer and less likelihood of flow separation associated with less aileron deflection. However, aeroelastic tailoring also results in an increase in the stress level in the composite wing skins, which could result in a weight increase to maintain the desired strength. Overall it appears that a performance increase is obtained by aeroelastic tailoring. Since trade-offs exist, the use of an integrated design approach incorporating aerodynamic, structural and control considerations would be beneficial (or necessary) for designs with aeroelastic tailoring.

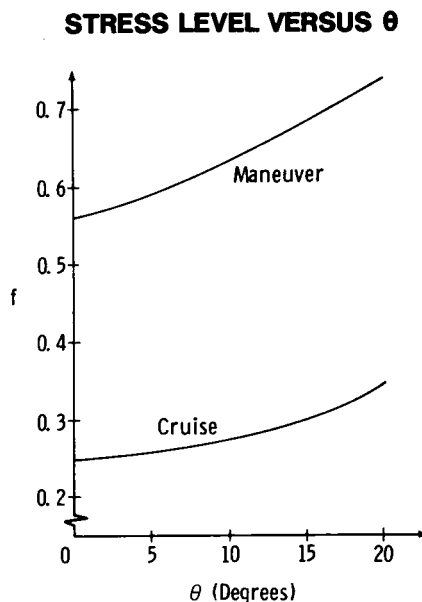


Figure 7

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